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VORTEX DEPINNING IN $\text{YBa}_2\text{Cu}_3\text{O}_7$: RESISTIVE TRANSITION IDENTIFICATION OF THE CROSSOVER FROM FLUX-CREEP TO FLUX-FLOW BEHAVIOR

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Analysis of resistive transitions of $\text{YBa}_2\text{Cu}_3\text{O}_7$ crystals reveals a scaling behavior which identifies the vortex-depinning critical field H_{cp} , hence the crossover in behavior from flux creep to flux flow. The inferred H_{cp} for $\text{YBa}_2\text{Cu}_3\text{O}_7$ crystals closely approximates the magnitude and temperature dependence of H_{cp} derived from penetration length measurements of thin films.

1. INTRODUCTION

A complete characterization of the resistive transitions of high- T_c materials necessitates an understanding of the temperature and field dependence of the energy barriers $U(T, H)$ which impede flux motion. Resistance measurements¹ at different fields H show clearly the importance of thermal activation over energy barriers (i.e., flux creep) where the resistance is proportional to $\exp(-U(T, H)/k_B T)$. In a complementary way, measurements of the penetration length λ at different H probe directly the curvature of these wells for small vortex displacements.²

Most importantly, both the resistance and the penetration length measurements share a common aspect by pointing to a field-dependent critical temperature $T_c(H)$ where $U(T, H)$ becomes negligible. In the resistance measurements³ this temperature is inferred by extrapolating the logarithmic slope $d(\ln R)/d(\ln T^{-1})$ to zero whereas in the penetration length measurements² this temperature is defined by extrapolating λ^{-1} to zero. Separately, the penetration length measurements show that in the field range $1 \text{ T} \leq H \leq 14 \text{ T}$ the linear dependence $H_{cp}^{1/2} \propto T$ is obeyed. We demonstrate here using a scaling argument that this same functional form for H_{cp} is manifest in the resistance transitions, shown in Fig. 1, of a $\text{YBa}_2\text{Cu}_3\text{O}_7$ crystal. Consequently, both measurements are consistent with the notion of a vortex-depinning

critical field $H_{cp}(T)$ which delineates the crossover from flux-creep to flux-flow behavior.

2. THE SCALING MODEL

The central assumption of our model is that there is a well-defined temperature $T_c(H)$ below which vortex motion is dominated by the presence of non-zero barriers and above which the vortices are free to flow unimpeded. At $H = H_{cp}$ where $U \sim k_B T$ there is no creep contribution to the resistivity ρ which can therefore be written in the

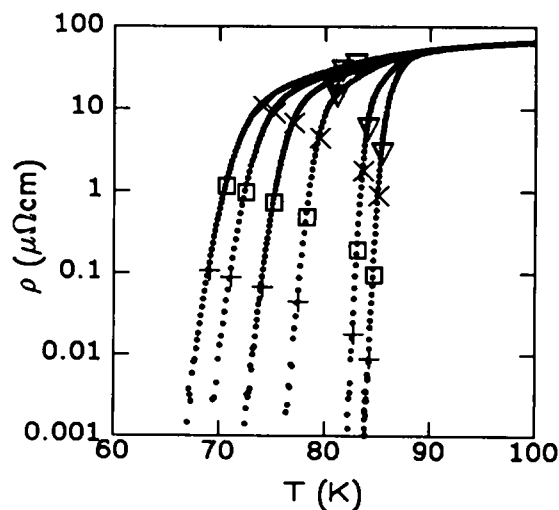


FIGURE 1
Resistive transitions at fields (H parallel to c -axis) of 1, 2, 5, 7.5, 10, and 12 T of a $\text{YBa}_2\text{Cu}_3\text{O}_7$ crystal.

form $\rho = H_{cp} \Phi_0 / c^2 \eta$, where Φ_0 is the flux quantum and η the vortex flow viscosity, assumed to be a constant.

With these assumptions, it is straightforward to analyze a family of $\rho(T)$ curves¹ taken at different fields such as shown in Fig. 1. We begin by choosing an arbitrary resistivity threshold, say $1.0 \mu\Omega \text{ cm}$ for the 1 T curve, and marking it with an identifier \times . In the flux flow regime the linear dependence of ρ on H_{cp} implies a linear scaling with H of the 1 T resistivity threshold. Thus $T_c(H)$ on the higher field curves can be identified and the locus of points (\times) plotted as shown in Fig. 1. Similar loci are shown for 1 T resistivity thresholds of $0.01 \mu\Omega \text{ cm}$ ($+$), $0.1 \mu\Omega \text{ cm}$ (\square) and $3.0 \mu\Omega \text{ cm}$ (∇).

3. RESULTS AND CONCLUSIONS

Having determined possible trajectories for $H_{cp}(T)$ in Fig. 1 which depend only on the initial guess of a threshold resistivity, we can now directly interpolate to find the dependence of H_{cp} on temperature. The resulting dependences for resistivity thresholds of $0.01 \mu\Omega \text{ cm}$ ($+$), $0.1 \mu\Omega \text{ cm}$ (\square), $1.0 \mu\Omega \text{ cm}$ (\times) and $3.0 \mu\Omega \text{ cm}$ (∇) are shown in the $H^{1/2}$ versus T plot of Fig. 2(a). For resistivity thresholds of $1.0 \mu\Omega \text{ cm}$ and smaller the agreement with the aforementioned $H_{cp}^{1/2} \propto T$ dependence found in penetration length measurements [see Fig. 2(a)] is excellent. We note that a higher resistivity threshold of $3.0 \mu\Omega \text{ cm}$ (∇) exhibits a pronounced deviation with positive curvature whereas lower resistivity thresholds ($+$ and \square) exhibit less pronounced deviations with increasing negative curvature.

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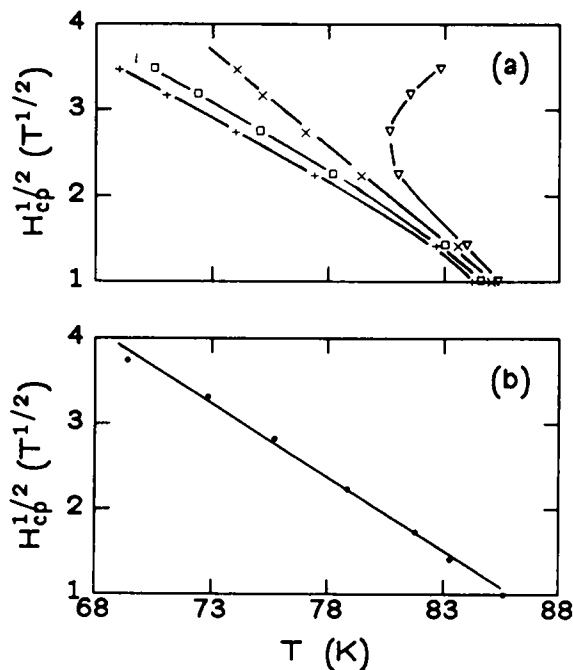


FIGURE 2
Plots of $H_{cp}^{1/2}$ vs T for (a) interpolated temperature dependences using the trajectories in Fig. 1 defined by the symbols ($+$, \square , \times , ∇) common to both figures and for (b) the penetration depth measurements.